10. Parsons, L.R. 1984. Use of microsprinklers for cold protection in an advective freeze. The Citrus Ind. 65:8–11.
11. Parsons, L.R., B.S. Combs, and D.P.H. Tucker. 1985. Citrus freeze protection with microsprinkler irrigation during an advective freeze. HortScience 20:1078–1080.
12. Parsons, L.R., T.A. Wheaton, and D.P.H. Tucker. 1986. Florida freezes and the role of water in citrus cold protection. HortScience 21:2, 175.
13. Parsons, L.R., T.A. Wheaton, D.P.H. Tucker, and J.D. Whitney. 1982. Low volume microsprinkler irrigation for citrus cold protection. Proc. Fla. State Hort. Soc. 95:20–23.
14. Parsons, L.R., T.A. Wheaton, and J.D. Whitney. 1981. Low volume microsprinkler undetree irrigation for frost protection of young citrus trees. Proc. Fla. State Hort. Soc. 94:55–59.
15. Parsons, L.R., T.A. Wheaton, and J.D. Whitney. 1982. Undertree irrigation for cold protection with low-volume microsprinklers. HortScience 17:799–801.
16. Wilcox, D. and F.S. Davies. 1981. Modification of air temperature and citrus leaf temperature with high volume undertree sprinklers. Proc. Fla. State Hort. Soc. 94:59–63.

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Mechanical Harvest of Red Raspberry as Affected by Training Systems

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Abstract. **Red raspberry (*Rubus idaeus* L, cv. Meeker) was grown with either 3-m or alternate 3-m and 1.5-m between-row spacing. Canes were trained as: a) pruned upright bundles, b) pruned and individually woven canes, or c) unpruned looped bundles, all secured to wires 1.5 m high. Training did not consistently affect yield as obtained with a Littau mechanical harvester. Fruit size was smallest in the unpruned bundles. The amount of fruit that dropped between or during harvests was substantial, but was similar for row spacings and training systems.**

The 4.5 to 5.5 $t \cdot ha^{-1}$ average annual yield of red raspberries in Oregon is below the crop potential (3) for the Meeker cultivar. Researchers and growers have experimented with training systems (4, 13), pruning techniques (1, 9, 12), and soil fertility (5, 10), and studied the effects of such treatments on plant population density, cane diameter, bud number, budbreak, berries per cluster, and their relationship to yield (8, 14). Many factors (cane population, fruits/lateral, fruit size) contribute to variations in yield, often compensating for each other (6, 7, 11). Characteristics that consistently and predictably relate to yield from mechanical harvesting and cultural practices that minimize fruit loss have not been identified.

High-density planting is one practice that may increase red raspberry yield. The harvesting machine will operate successfully in closed-space rows; thus, higher than normal cane density may be established and harvested. There is little information on plant response to high density. These studies determined the effect of cane population and training system on plant and fruit characteristics and efficiency of mechanical harvesting.

The red raspberry, ('Meeker') was established in two adjacent plantings at North Willamette Experiment Station (Aurora, Ore.) in 1980, one with 3 m between rows (standard) and the second with alternate 1.5 m and 3 m between rows (modified). Each plot consisted of one hedgerow 30 m long. Within a given area, the modified planting contained 33% more individual rows than the standard. A Littau mechanical harvester was operated in the 3-m between-row spaces.

The Littau harvester is a self-propelled over-the-row machine. Fruits are dislodged by flailing rods that pass along both sides of the row and transmit the shaking action throughout the plant. Detached fruits drop to spring-loaded overlapping catch plates, then roll onto pocket belt conveyors that move the fruit through a pneumatic cleaner onto an inspection belt and into containers.

Three training systems were compared: a) upright bundles pruned to 1.8 m, b) individually woven canes pruned to 1.8 m, and c) looped bundles of unpruned canes 1.8–2.4 m. All canes, individual or bundled, were secured to a wire 1.5 m from the ground. Plots were replicated three times in each planting.

Fruit yield and size and cane number/plot were recorded for all treatment combinations. A random sample of 10 canes/plot was used to estimate cane diameter, bud number/60-cm cane midsection, fruiting laterals/60-cm section, and fruits/lateral (one lateral 45 cm from base) for the woven system in 1982 and 1983. In 1984 and 1985, data were taken on all three training systems.In 1984, 5-m sections of each plot were gleaned for dropped fruit after each harvest. In 1985, dropped fruit was gleaned immediately before harvest and immediately after harvest to identify loss occurring in the interval between harvests and loss during harvest.

Harvest data and cane measurements were subjected to two-way analysis of variance in comparisons of training methods. Correlation coefficients (r values) were calculated for identifying relationships between harvest data and cane characteristics. Because the two-row spacings actually constituted independent experiments, the yields and cane numbers from the standard and modified plantings were compared using paired t tests each year.

Training method did not affect mechanically harvested yield in the modified planting (Table 1). In the standard planting, differences in yield were attributable to training method only in 1983 and 1984. Differences in fruit size, when present, showed that canes in looped bundles produced the smallest fruit (Table 1). The small fruits in terminal clusters of the unpruned canes apparently reduced the average berry size in this treatment, a practical consideration in hand picking but of little importance when machine picking.

The inconsistent production of woven plots with evenly spaced canes with the buds well-exposed to light is explained in that woven plots generally had significantly fewer trainable canes/m^2 than upright or looped plots (Table 1). All canes too short to reach the training wire or too delicate to support an adjacent cane were removed at training. The upright bundle training system allowed for the retention of marginally acceptable canes, since even the smallest canes not long enough for looping could be secured in a bundle with other canes.

The population of trained canes is the factor most consistently associated with yield. Yield/m^2 was correlated with canes/m^2 in 1982, 1983, and 1984 (r = 0.649, 0.501, and 0.706, respectively). Yield/m^2 was correlated with cane diameter (r = 0.716) only in 1983. In 1982 and 1983, number of buds/60-cm cane section was negatively correlated with yield (r = −0.623 and −0.584). Other plant characteristics measured had no significant relationship to yield.

Plant competition for light, water, and nutrients may, in part, explain the failure of the modified row spacing to increase yield in proportion to the increase in cane population (Table 2). Despite significantly greater number of canes in the modified planting (Table 2) and the correlation of cane population and yield (prior), yield in the modified planting was greater only in 1984 (Table 2).

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Table 1. Relationship of training and row spacing of red raspberries to mechanically harvested fruit and cane growth.

Training system	Yield (g·m^{-2}) 1982	1983	1984	1985	Berry size (g/berry) 1982	1983	1984	1985	Canes/m^2 1982	1983	1984	1985
Standard (3-m between-row) spacing												
Upright	857	503 a[a]	584 a	399	2.8 a	3.0 b	3.0 a	2.6 A	6.4	4.5 A	6.2 a	5.0
Woven	885	490 a	489 c	401	2.8 a	3.1 a	2.9 b	2.5 AB	5.4	2.9 B	4.3 c	4.5
Looped	783	423 b	542 b	359	2.6 b	2.9 c	2.8 c	2.4 B	6.4	3.4 B	5.5 b	4.2
Modified (alternate, 3-m and 1.5-m between-row) spacing												
Upright	865	457	636	383	2.6	2.8 B	2.9	2.6 b	8.0	4.1	7.2 a	6.1
Woven	898	412	538	403	2.7	2.9 A	2.9	2.4 b	6.4	3.0	5.5 c	6.0
Looped	970	488	646	411	2.6	2.7 C	2.8	2.4 b	9.2	3.6	6.2 b	5.3

[z]Mean separation within columns by Duncan's multiple range test, $P = 5\%$ (lower case); 1% (upper case).

Table 2. Effect of row spacing on cane population density[z] and yield[z] of 'Meeker' red raspberry.

Row spacing	Canes/m^2 1982	1983	1984	1985	Yield (g·m^{-2}) 1982	1983	1984	1985
Standard[y]	6.1	3.6	5.3	4.6	842	472	538	386
Modified[x]	7.9	3.6	6.3	5.8	906	451	607	399
Significance	*	NS	*	**	NS	NS	**	NS

[z]Values are combined average of all training systems.
[y]Three meters between rows.
[x]Alternate 3 m and 1.5 m between rows.
NS,*,**Nonsignificant or significant at the 5% or 1% levels in paired *t* test, respectively.

Related research on cane orientation reported in 1984 (13) showed that at a cane height of 80 cm, 43% of the laterals were oriented toward the narrow between-row space (1.5 m) and 56% were oriented toward the wide (3-m) between-row space. The laterals that were oriented toward the narrow row space averaged fewer fruits/lateral (9.5) than the laterals that were oriented toward the wide row space (11.5).

The percentage of budbreak (floricane buds that developed a fruiting lateral) from all woven plots in both row spacings averaged 69% for the 4-year period, indicating a loss of nearly one-third the crop potential. In 1984 and 1985, budbreak also was counted in the upright and looped bundle plots, but was not significantly affected by training system and was not correlated with cane population density (data not shown).

The amount of gleaned fruit in 1984 averaged 22% of the total yield in the standard planting and 21% of the total yield in the modified planting. These percentages approximate the loss of 25% reported by Cormack and Waister in Scotland (2), but are greater than the 10% to 20% losses estimated by commercial growers in the Pacific Northwest. Neither weight nor percentage of fruit gleaned preharvest and postharvest was related to training system in 1985.

In 1985, 34% of the gleaned fruit in the modified row spacing was preharvest drop compared to 43% preharvest drop in the standard. Rate of fruit ripening may have been decreased in plots with modified spacing and higher cane populations, reducing fruit drop. Postharvest gleanings in 1985 were from 13.4% to 18.2% of the total ripe fruit. Neither the weight nor percentage of the postharvest gleaning was affected by training system.

The price for berries and unit production costs ultimately determine the value of potential production increases. The initial increase in cost for plants, posts, and wire, and the recurring costs for labor in the modified row spacing, with the one-third increase in number of rows, will likely offset the modest production gains that are possible.

Literature Cited

1. Brierly, W.G. 1931. Effect of height of pruning on size of berries and yield in the Latham raspberry. Minn. Agr. Expt. Sta. Bul. 281.
2. Cormack, M.R. and P.D. Waister. 1976. Sources of yield loss in machine harvested raspberry crops. Acta Hort. 60:21–26.
3. Crandall, P.C. 1974. Raspberry training systems. Proc. Lower Mainland Hort. Improvement Assn. 16:22–23.
4. Crandall, P.C. 1979. Factors affecting raspberry yields. Proc. Lower Mainland Hort. Improvement Assn. 21:27–28.
5. Crandall, P.C., D.F. Allmendinger, S.D. Chamberlain, and K.A. Biderbost. 1974. Influence of cane number and diameter, irrigation, and carbohydrate reserves on the fruit number of red raspberries. J. Amer. Soc. Hort. Sci. 99:524–526.
6. Crandall, P.C., J.D. Chamberlain, and K.A. Biderbost. 1974. Cane characteristics associated with berry number of red raspberry. J. Amer. Soc. Hort. Sci. 99:370–372.
7. Darrow, G.M. and G.F. Waldo. 1933. Raspberry and blackberry cane measurements. Proc. Amer. Soc. Hort. Sci. 30:269–274.
8. Fejer, S.O. 1979. Note on effects of cane density in red raspberry. Gartenbauwissenschaft 44:136–137.
9. Johnston, S. and Loree, R.E. 1927. Pruning the red raspberry. Mich. Agr. Expt. Sta. Spec. Bul. 162.
10. Lawson, H.M. and P.D. Waister. 1972. The response to nitrogen of a raspberry plantation under contrasting systems of management for weed and sucker control. Hort. Res. 12:43–55.
11. Locklin, H.D. 1932. Effects of different methods of pruning raspberries on earliness, weight of fruit and yield. Proc. Wash. State Hort. Assn. 27:185–189.
12. Martin, L.W., E. Nelson, and M.H. Chaplin. 1980. Plant and fruit measurements of 'Meeker' red raspberry related to pruning height and nitrogen application. Acta Hort. 112:157–161.
13. Nelson, E. and L.W. Martin. 1984. Effects of row spacing, plant spacing, and training method on 'Meeker' red raspberry cane characteristics and yield. Proc. Western Wash. Hort. Assn. 74:148–152.
14. Pelofske, P.J. and L.W. Martin. 1982. A comparison of machine harvest yields and yield estimates from some red raspberry cultivars and selections. Proc. Western Wash. Hort. Assn. 72:172–174.